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INTERFERENCE EFFECTS OF LONGITUDINAL FLAT PLATES

ON LOW-DRAG AIRFOILS

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SUMMARY

Three airfoils, including a conventional NACA 23021 and the NACA 65,3-418 and 65,2-422 (approx.) sections, were tested with an intersecting flat plate normal to the span as a preliminary study of interference effects on airfoils. The results indicate small interference effects for the first two airfoils and larger effects on the NACA 65,2-422 (approx.) section, which has previously been shown to be probably unconservative with respect to separation. It is concluded that airfoils known to be conservative should be used, in the absence of tests, for inboard wing sections subject to nacelle and fuselage interference.

INTRODUCTION

The NACA low-drag airfoils first investigated, and most of those for which data are presented in reference 1, were intended to be of conservative design to avoid serious separation difficulties even with rough leading edges. The thickness, camber, and position of minimum pressure of these airfoils were chosen to produce conservative pressure recoveries over the rearward part of the upper surface. The resulting earlier airfoils were suitable for pursuit airplanes and most of them were intended for this application.

Later applications to long-range bombers with heavy wing loadings resulted in an increase in the airfoil thickness ratios and cambers to the point where it was feared that excessive drag coefficients resulting from turbulent separation might be experienced in the useful flight range of lift coefficients if the leading edges became roughened. An investigation of the effect of

extreme leading-edge roughness on airfoils in the doubtful range (reference 2) indicated that the conservative range of airfoil design was probably being exceeded. It was thought, moreover, that airfoils showing a tendency to break down locally when the leading edges were roughened might also break down in the presence of other disturbances such as disturbances caused by fuselage and nacelle interference. The possibility also existed that the flow over the airfoil of a fully developed turbulent boundary layer, as at the wing-fuselage juncture, might be even more effective than leading-edge roughness in promoting local flow breakdowns.

The present investigation was accordingly started to study the effects on typical airfoil sections of an intersecting flat plate normal to the span. The leading edge of the flat plate was roughened to produce turbulent boundary layers. The set-up accordingly simulated reasonably well the boundary-layer conditions at the intersection of a wing with a large flat-sided fuselage. The present tests are considered preliminary to more extensive and detailed interference investigations, which will be conducted when time permits.

METHODS

The arrangement of the airfoils and flat plates is shown in figures 1 and 2. In some cases the flat plate was placed off the center line for practical reasons. The tests were made in the NACA two-dimensional low-turbulence pressure tunnel by the methods described in reference 1. The drag coefficients of the airfoil-flat plate combinations were evaluated by the integration of results obtained by the wake-survey method at numerous spanwise stations. The drag of the flat plate supported from the tunnel wall was measured by the wake-survey method.

The interference drag coefficient, Δc_d, was obtained by subtracting from the drag coefficients of the combination the drag coefficients of the flat plate and the airfoil section as measured separately. The interference drag coefficient, Δc_d, is based on an area equal to the airfoil chord squared. The values presented are for two intersections represented by the two sides of the flat plate.

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The roughness applied to the leading edge of the flat plate for all tests and to the leading edge of the airfoil for some tests was similar to that described in reference 2, except that the roughness was applied directly to the model surfaces without the use of cellulose tape.

RESULTS AND DISCUSSION

The drag coefficients obtained for the flat plate are shown in figure 3. The drag coefficients and Reynolds number shown on this figure are based on the area and length, respectively, of the flat plate.

The interference drag coefficients obtained are plotted against lift coefficients for the NACA 23021, 65,3-418, and 65,2-422 (approx.) airfoils in figure 4. Results are presented for the NACA 23021 and 65,2-422 (approx.) airfoils with the airfoil leading edges rough as well as smooth. The results show that the interference is small at low lift coefficients except possibly for the NACA 65,2-422 (approx.) airfoil with roughened leading edge. The very small interferences shown at low lift coefficients are attributed to the decrease in wetted area of the plate when it intersects the airfoil. This decrease in wetted area appears very nearly to compensate for the drag increase that is associated with the disturbance of the laminar flow over the airfoil.

The interference increases with increasing lift coefficients in all cases. This increase is moderate for the NACA 23021 and 65,3-418 airfoils up to lift coefficients of about 1.1. In the case of the NACA 65,2-422 (approx.) airfoil the increase is more rapid at lift coefficients above about 0.8; the interference at a lift coefficient of 1.0 being nearly twice that for the NACA 23021 section and three times that for the NACA 65,3-418 section. The jog in the curve for the NACA 65,3-418 section at a lift coefficient of about 0.7 occurs near the limit of the low-drag range for this airfoil, where the transition moves forward close to the leading edge on the upper surface. At higher lift coefficients, less laminar layer is present on the upper surface to be affected by the flat plate and the interference drag accordingly fails to increase with lift coefficients in this range.

The effect of the flat plate on the NACA 23021 airfoil with a roughened leading edge is very similar to that on the smooth airfoil. In the case of the NACA 65,2-422 (approx.) airfoil the flat-plate interference rises sharply at a lift coefficient of only about 0.6. This curve could not be extended to higher lift coefficients because extensive local separation made reliable drag measurements impossible by the methods used.

Lift curves for the three airfoils with intersecting flat plates and for the airfoils alone are presented in figures 5 to 7. In general, the presence of the flat plate is shown to have no serious effects on the lift characteristics.

The effects of an intersecting flat plate are shown to be much less serious than those of rough leading edges (reference 2). Sharp increases in the interference drag coefficients at comparatively low lift coefficients occurred for only the NACA 65,2-422 (approx.) section with rough leading edge, which had previously been indicated to be unconservative (reference 2).

The possibility of a complete flow breakdown between an engine nacelle and fuselage on an airplane using a wing section such as the NACA 65,2-422 (approx.) airfoil was considered. A typical nacelle model was accordingly mounted upon this airfoil model and tested with and without the flat plate with and without leading-edge roughness. The flat plate and nacelle were arranged to simulate a conventional arrangement of nacelle and fuselage side for a large bomber. Local flow breakdowns and the limited length of span that could be surveyed prevented accurate results from being obtained. The results that were obtained, however, indicated qualitatively that the effect of adding the flat plate to the wing-nacelle combination was favorable. The interference caused by the flat plate was small and favorable (Δc_d about -0.001) with the leading edge smooth and much more favorable (Δc_d about -0.006) with the leading edge rough. This unexpected result does not indicate that such a combination is favorable for low drag. Examination of the wake surveys showed that the nacelle caused a flow breakdown, which extended spanwise on the wing for a considerable distance. The flat plate served to limit the extent of this flow breakdown without appreciably affecting the severity of the separation between the plate and the

nacelle. Considerable caution should therefore be exercised in using such thick and highly cambered low-drag airfoils in combination with nacelles.

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CONCLUSIONS

The results of these preliminary tests indicate that, in the absence of tests of the proposed arrangement, airfoils definitely known to be conservative should be used for inboard sections subject to nacelle and fuselage interference. Although the limits of the conservative range are not clearly defined, the resulting interference should not be large if sections as conservative as the NACA 65,3-418 are used with junctures similar to those of a flat plate normal to the span.

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REFERENCES

1. Jacobs, Eastman N., Abbott, Ira H., and Davidson, Milton: Preliminary Low-Drag-Airfoil and Flap Data from Tests at Large Reynolds Numbers and Low Turbulence, and Supplement. NACA A.C.R., March 1942.

2. Jacobs, Eastman N., Abbott, Ira H., and Davidson, Milton: Investigation of Extreme Leading-Edge Roughness on Thick Low-Drag Airfoils to Indicate Those Critical to Separation. NACA C.B., June 1942.

ERRATA ON FIGURES

The values of section lift coefficient (figs. 4 to 7) should be corrected by the following equation

$$c_l(\text{corrected}) = 0.965c_l + 0.011$$

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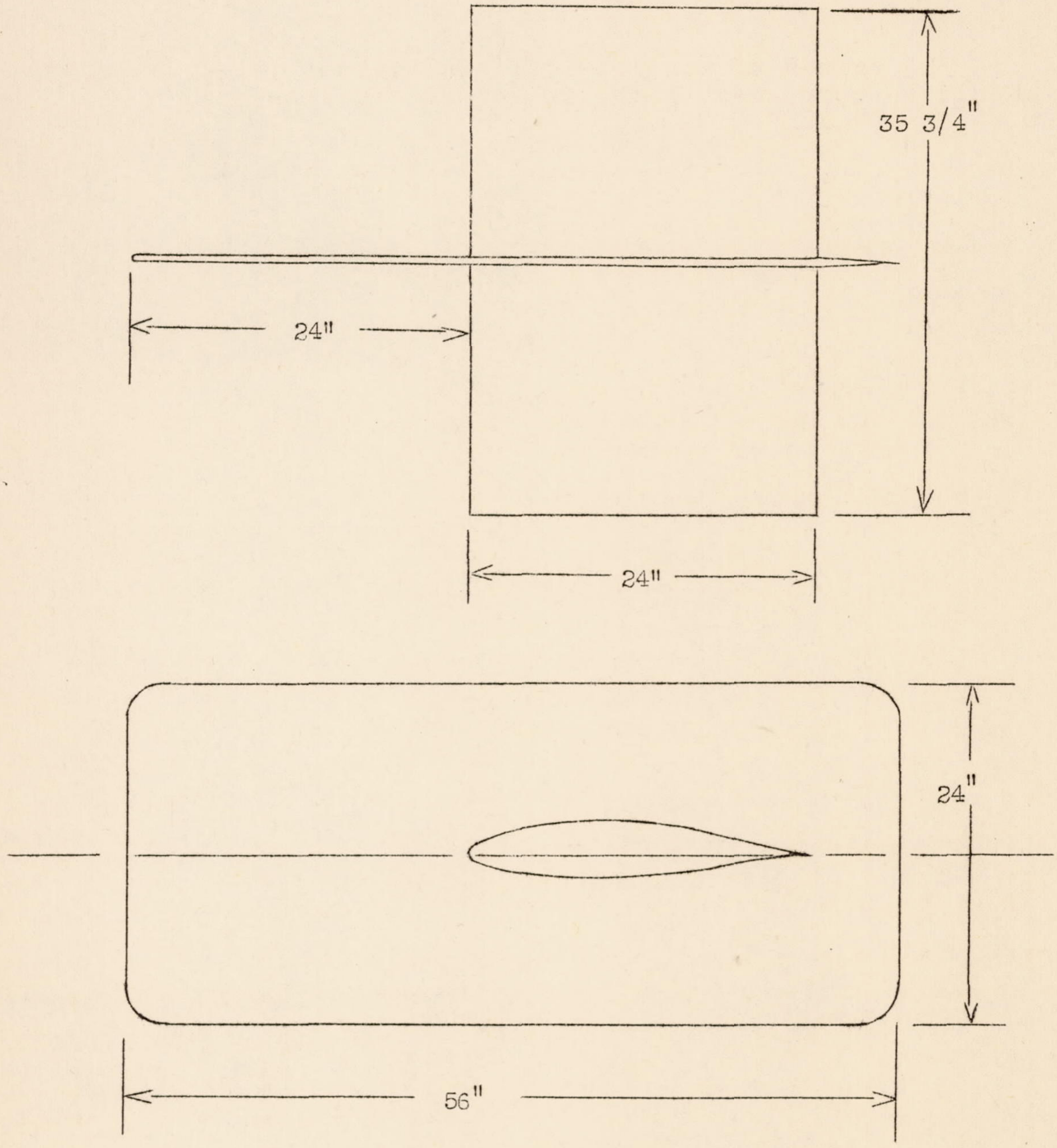

Figure 1.- Arrangement of airfoil and intersecting flat plate.

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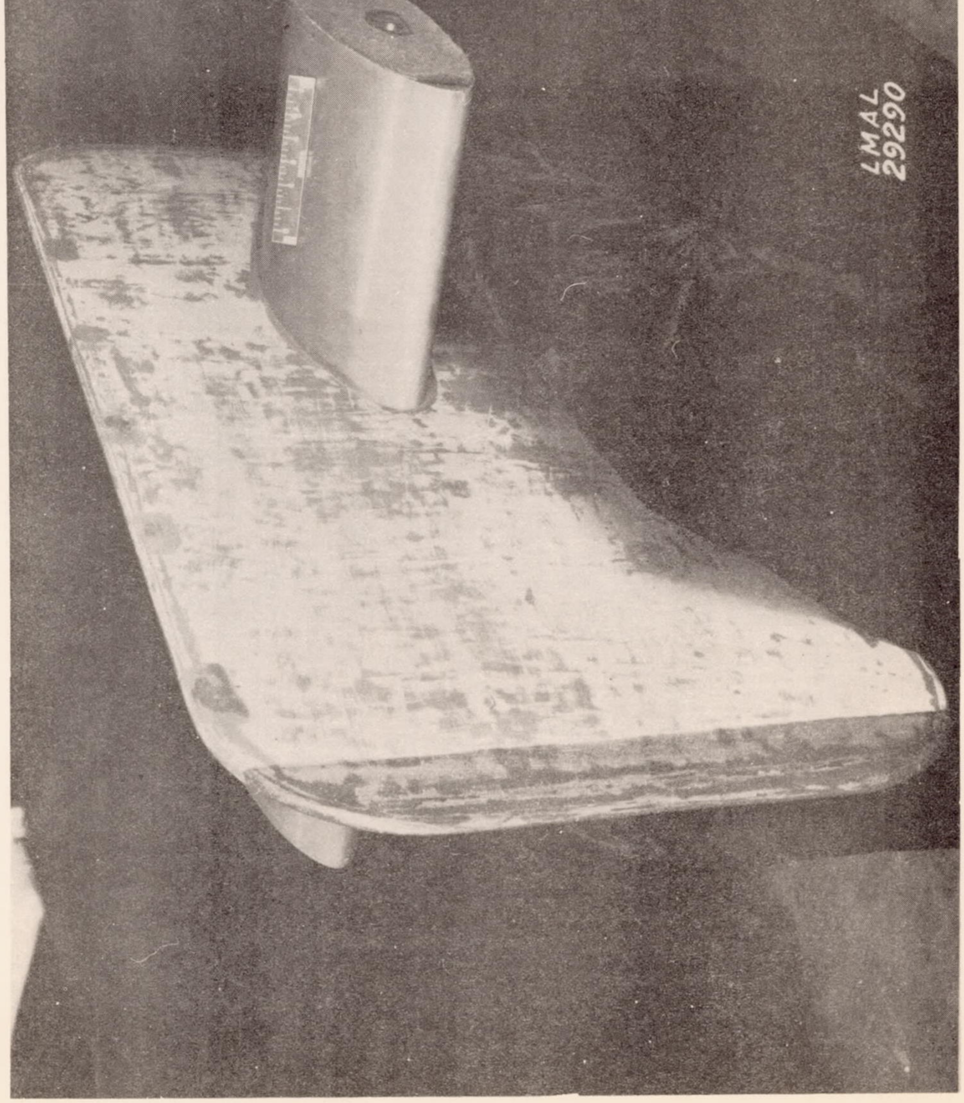

FIGURE 2. - AIRFOIL MODEL WITH INTERSECTING FLAT PLATE.

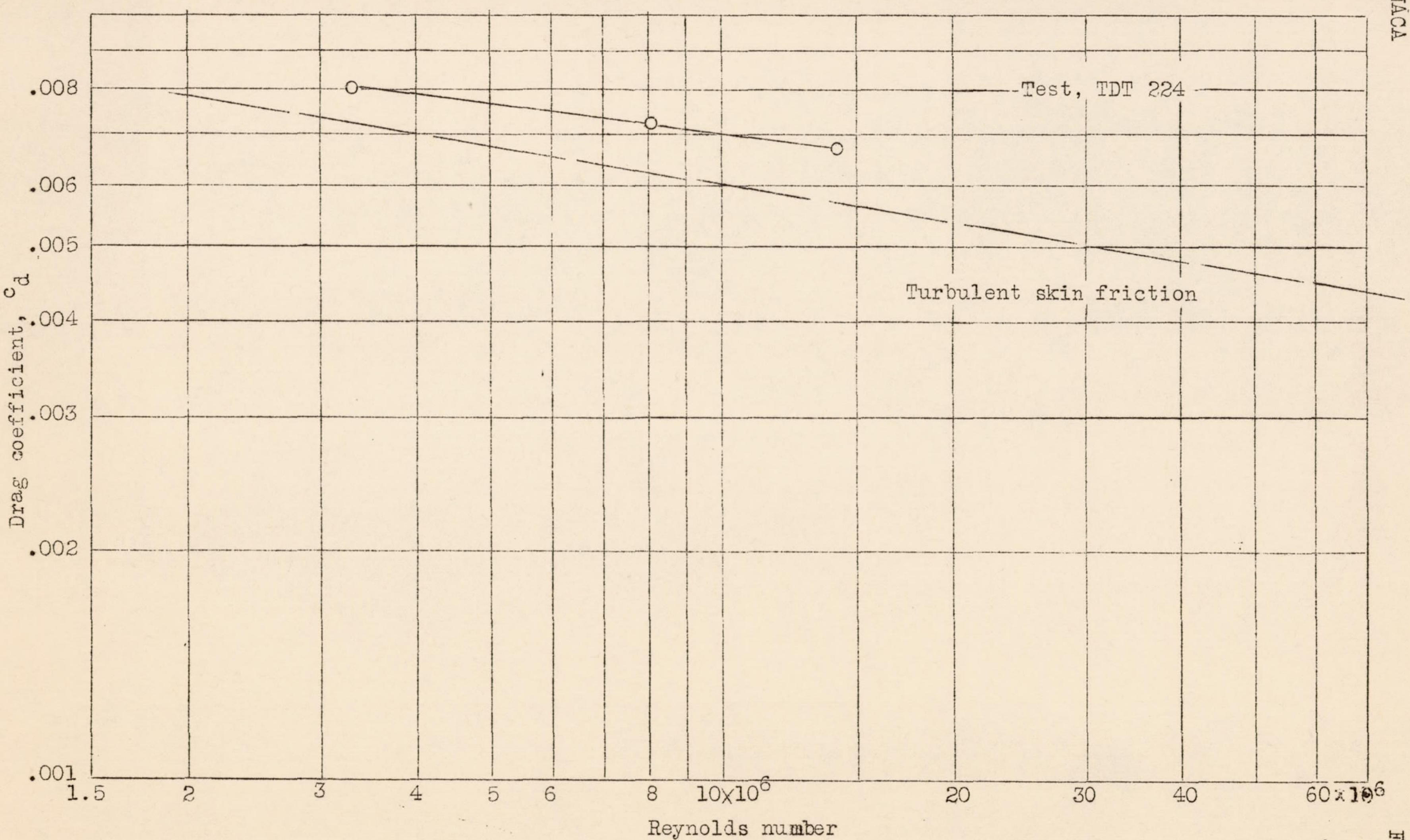

Figure 3.- Drag coeffient of flat plate alone with roughness at leading edge.

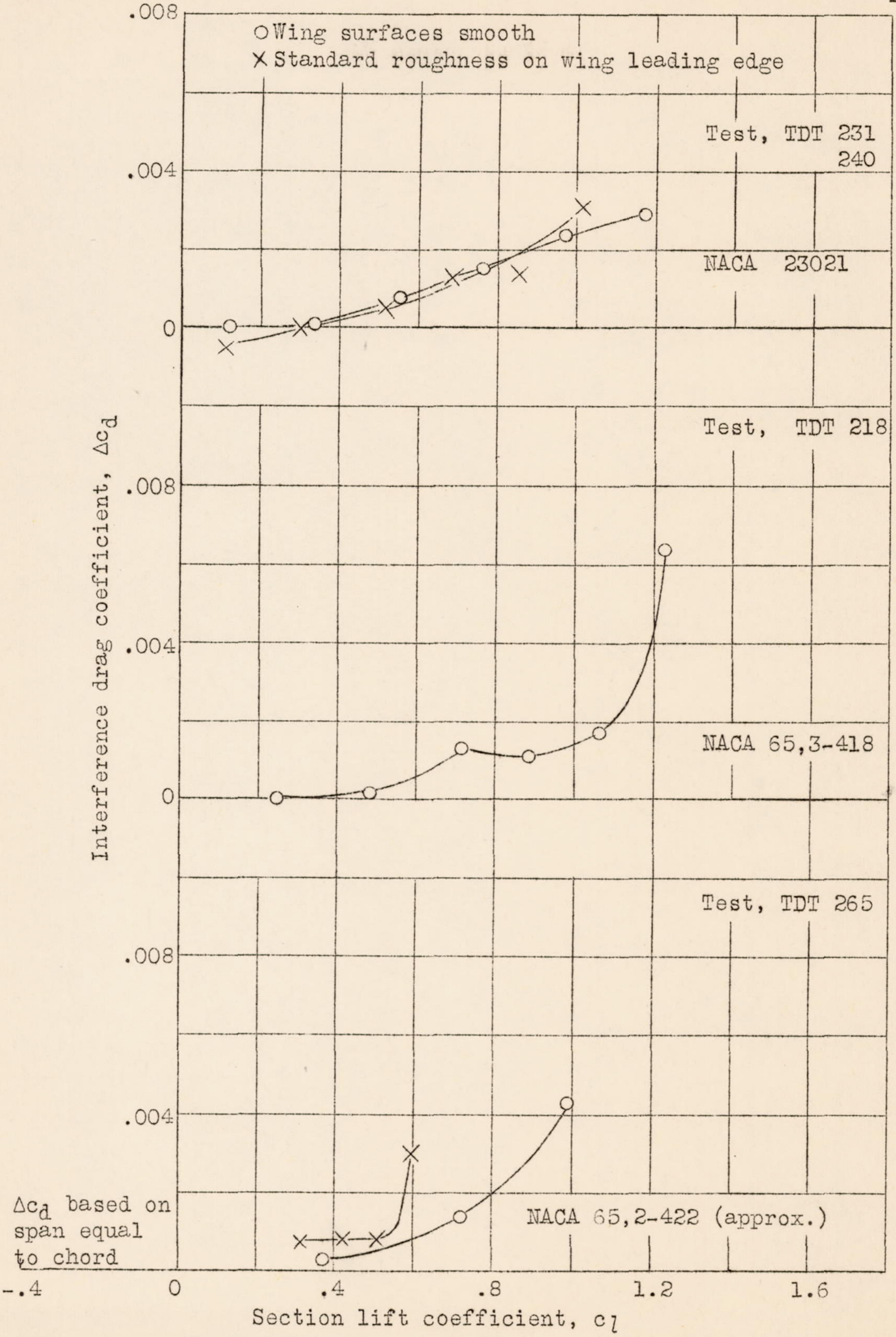

Figure 4.- Interference drag coefficients for three airfoils with intersecting flat plates. $R=6\times10^6$

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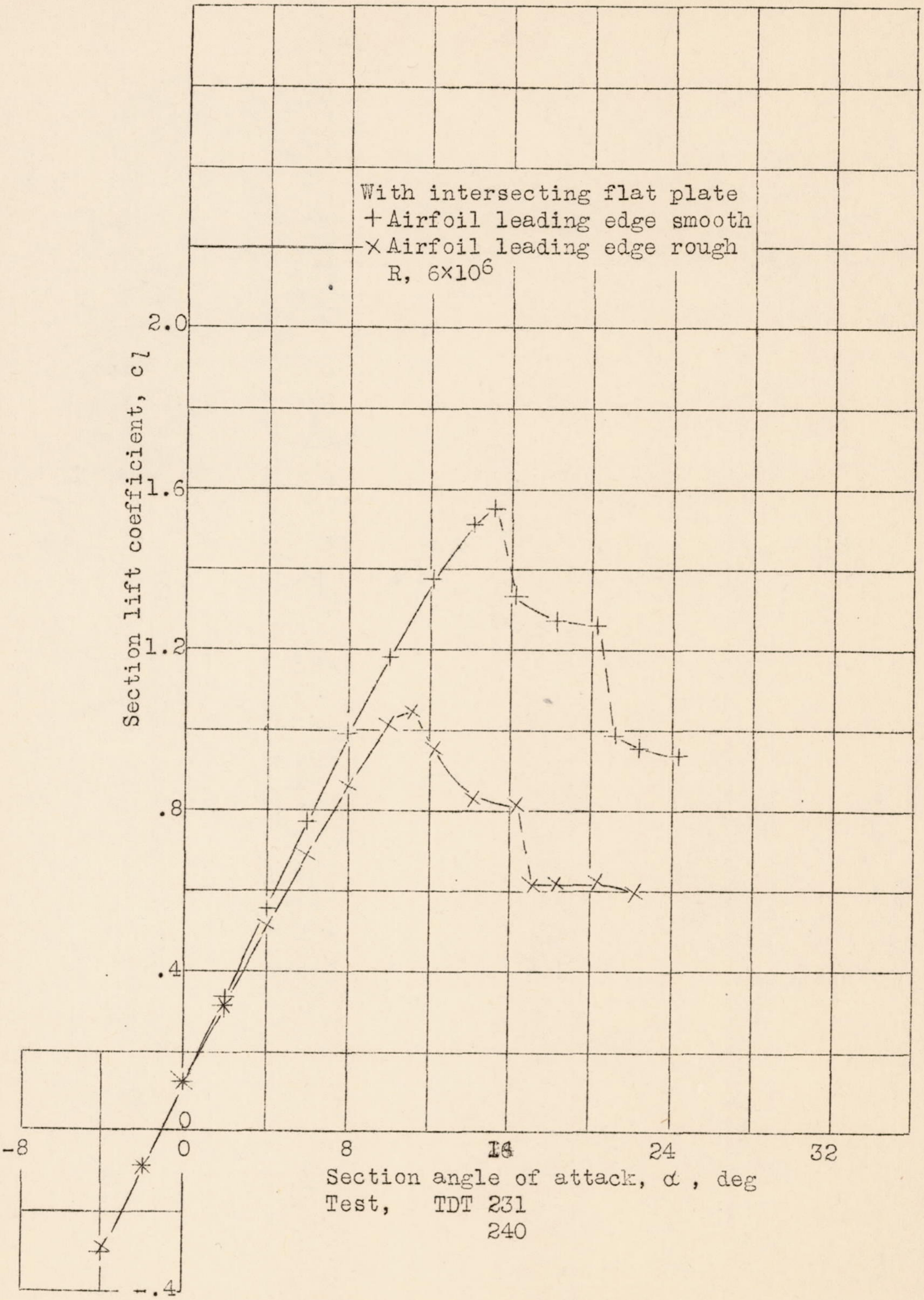

Figure 5.- Lift characteristics of NACA 23021 airfoil with intersecting flat plate.

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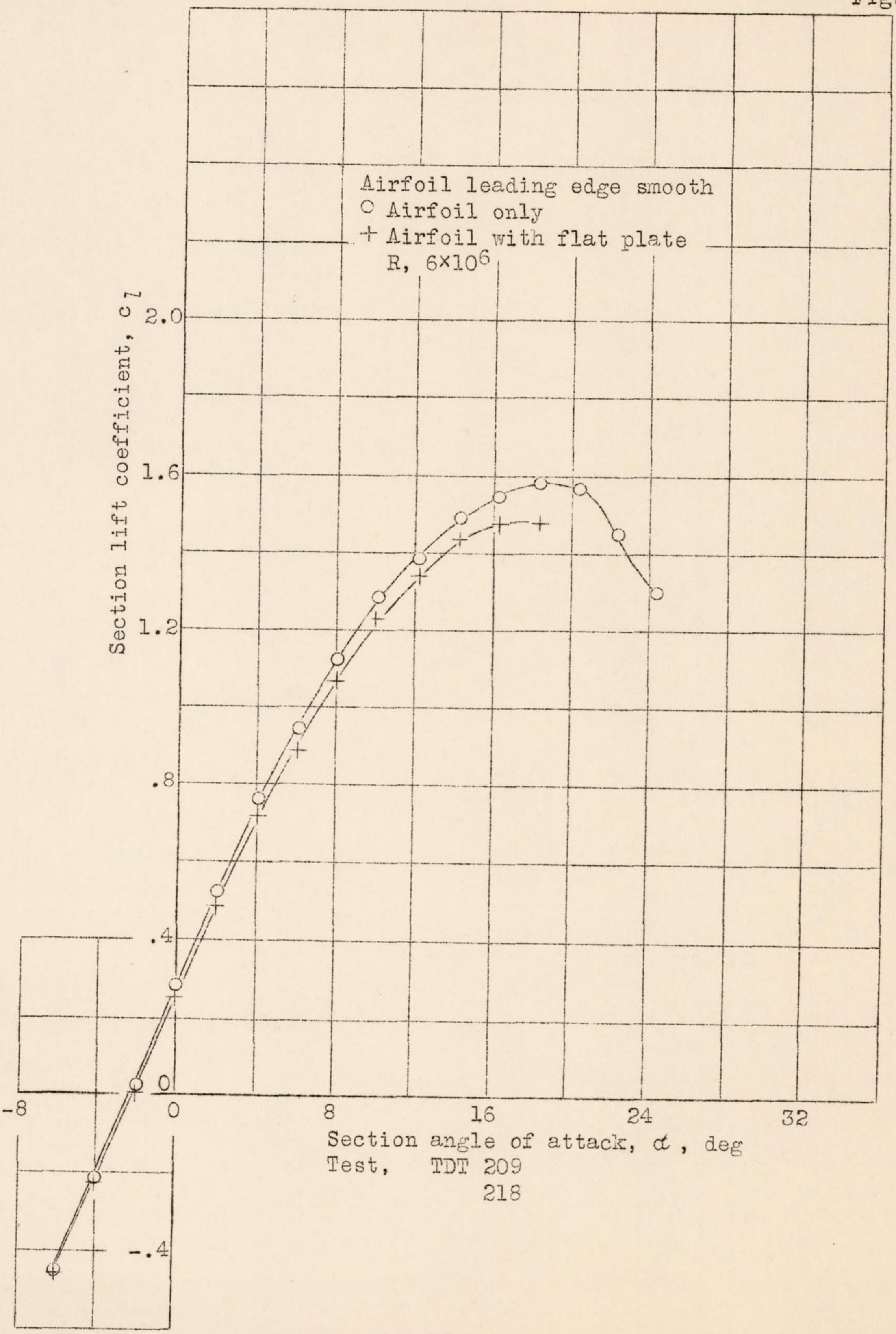

Figure 6.- Lift characteristics of NACA 65,3-418 airfoil with and without intersecting flat plate.

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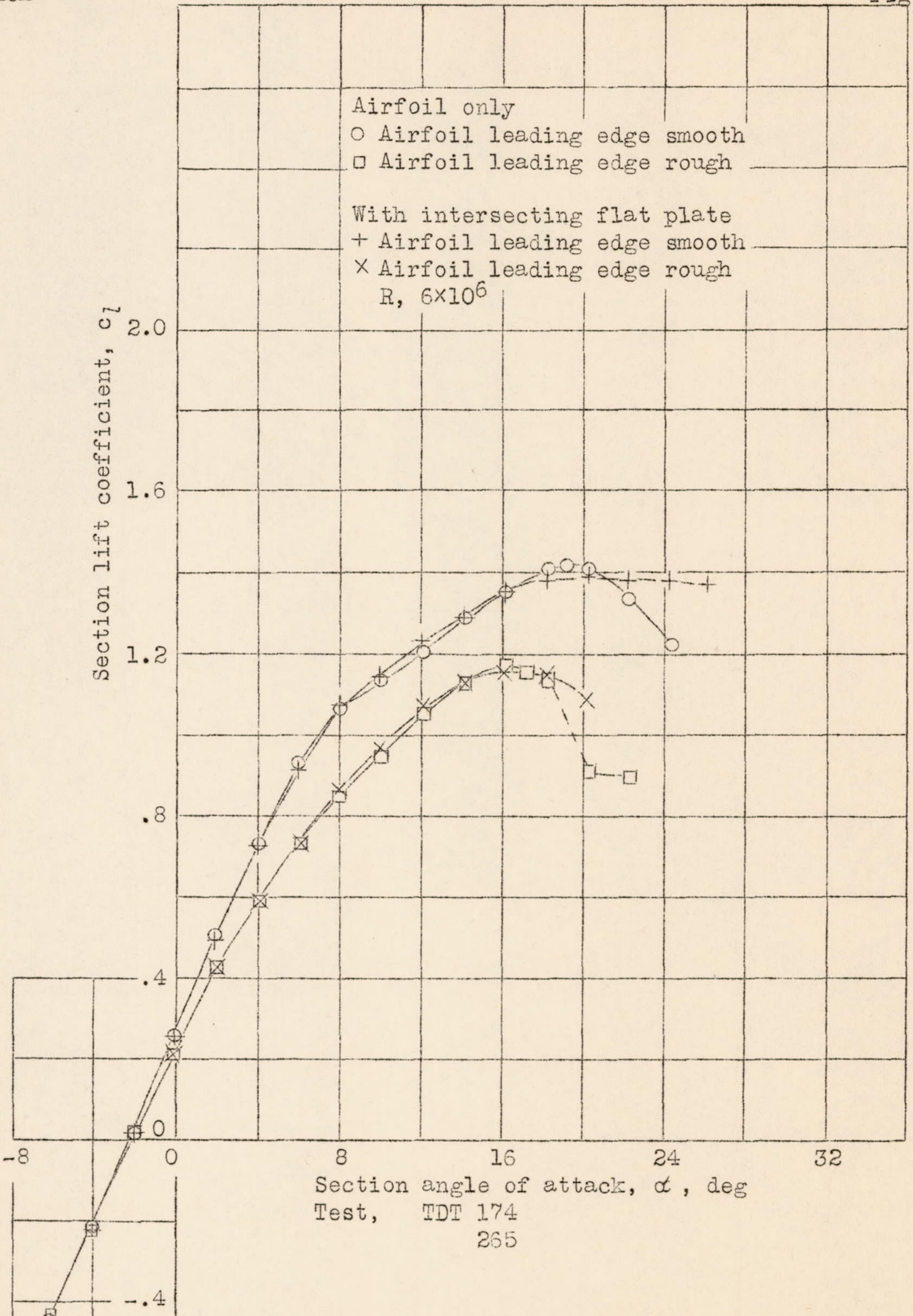

Figure 7.- Lift characteristics of NACA 65,2-422 airfoil (approx.) with and without intersecting flat plate.